T2* and ADC Simultaneous Measurements of in vivo Symptomatic and Asymptomatic carotid atherosclerotic plaques Using 2D ss-SGE-DWEPI Technique

Seong-Eun Kim[1], Eun-Kee Jeong[1], Xianfeng Shi[2], Gerald S Treiman[3,4], and Dennis L Parker[1]

[1]UCAIR Department of Radiology, University of Utah, Salt Lake City, Utah, United States, [2]UCAIR Brain Research Insititute, University of Utah, [3]Department of Surgery, University of Utah, [4]Department of Veterans Affairs, VASLCHCS

INTRODUCTION: Many Studies have shown that hemorrhage is highly correlated with neurologic events in patients with carotid stenosis [1-2]. Hemorrhage is therefore an important plaque component and can be detected with MR thrombus imaging [3]. It has been reported that Type I (fresh) hemorrhage occurred more often in patients with symptomatic plaques [4]. A previous ex vivo DWI study reported that the ADC in hemorrhage varies according to the processes that occur during the successive phases of aging [5]. Our 2D-IMIV-DWEPI sequence has demonstrated the ability of in vivo DWI to separate hemorrhage, lipid and arterial wall [6]. Iron has consistently been found in higher concentrations in atherosclerotic plaque compared to vessel tissue [7]. Iron may be incorporated into hemoglobin or bound to the storage proteins ferritin and hemosiderin, both of which cause measurable changes in local magnetic field homogeneity [6]. It has been reported that intraplaque T_2* measurement distinguished symptom-producing from non-symptomatic plaques in patients with carotid atherosclerosis [8]. We have developed a novel 2D singleshot spin-/gradient echo- diffusion weighted EPI (2D ss-SGE-DWEPI) sequence that can measure simultaneously the diffusivity and T_2^* of water protons in carotid plaque. The purpose of this study was to determine retrospectively if T2* and ADC value obtained from a 2D ss-SGE-DWEPI sequence can simultaneously depict differences between symptomatic and asymptomatic carotid atherosclerotic plaque.

METHOD: 2D ss-IMIV-DWEPI was modified to create the additional readout of a gradient echo (GE EPI) as shown in Fig.1. A pair of refocusing and inversion (RI) 180º RF pulses immediately follows the excitation 90° pulse to confine the reduced phase FOV for interleaved multiple slice imaging (IMIV). The diffusion sensitized gradients were applied before and after the RI pulses. After a diffusion weighted spin echo (SE EPI) is formed at TE, this signal further evolves with T_2* decay. A gradient echo (GEPI) provides the signal of T_2* decay during ΔTE caused by local field variation. The signal equations of two echoes are described in Eqs (1) and (2). To evaluate the feasibility of T_2* measurement with 2D ss-SGE-DWEPI, MRI studies of five symptomatic and five asymptomatic patients with hemorrhage positive atherosclerosis were performed on a Siemens Trio 3T MRI scanner with home built carotid coils. The imaging parameters for 2D ss SGE-DWEPI were: ΔTE=42ms TR=3000ms, imaging matrix = 160x40, 2 mm slice thickness. The in-plane spatial resolution for data acquisition was 1.0x1.0mm. Scan time was 2:24 min for 42 magnitude averages. DWI with b=0 and 500 s/mm^2 were interleaved. The ADC and T_2* maps were calculated and displayed using IDL. While ADC maps were created only using SE DWI, T_2* maps were created using two echoes images with b=0. 3D MPRAGE and T1w images were acquired at the same slice locations as the ADC and T2* maps.

$$S_{SE}(\vec{r},t) = S_0(\vec{r})(e^{-b.D})e^{-\frac{TE}{T_2(\vec{r},t)}} \quad (1)$$

$$S_{GE}(\vec{r},t) = S_{SE}(\vec{r},t)e^{-\frac{\Delta TE}{T_2^*(\vec{r},t)}} \quad (2)$$

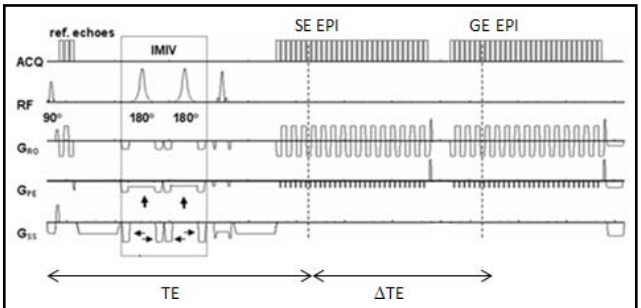

Fig.1 2D ss-SGE-DWEPI pulse sequence diagram

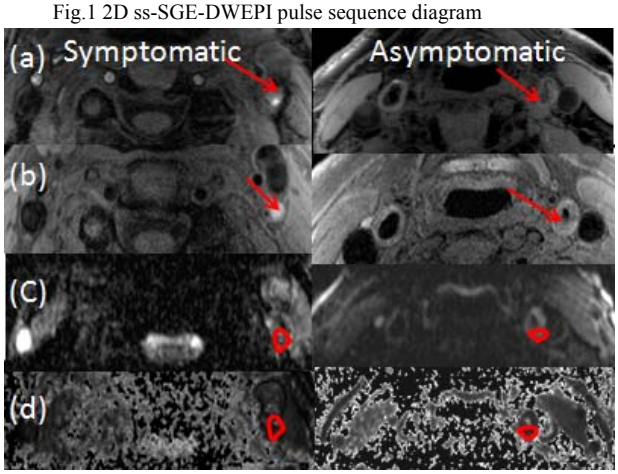

Fig.2 MP RAGE (a), T1w (b), ADC (c) and T_2*(d) maps from symptomatic and asymptomatic patients.

RESULTS: Table 1 Mean T_2*, T_1 and ADC values from 10 patients

	Symptomatic	Asymptomatic	P value
T2*(ms)	23±3.8	39±5.8	p<0.001
ADC (10^{-3}mm^2/s)	0.85±0.24	1.41±0.48	p=0.003

Three ROIs per each patient were selected in visible plaque. The mean T_2* and ADC values for plaque obtained from the 10 subjects are summarized in Table 1. Symptomatic compared to asymptomatic patients had significantly lower plaque T2* (p<0.001) and ADC (p=0.003) values. Our T_2* value is close to the value reported previously [8]. Fig 2 displays 3D MPRAGE, T1w images, T_2* and ADC maps from a symptomatic and an asymptomatic subject, each with intramural hemorrhage. The T_2* and ADC values obtained from the red ROIs in Fig. 2 were 24/35 ms and 0.91/1.25x10^{-3}mm^2/s, respectively.

DISCUSSION: We found that symptomatic plaque has a significantly lower ADC compared to values obtained from asymptomatic plaque. Previous ex vivo study reported that the ADC of fresh hemorrhage (0.72x10^{-3}mm^2/s) is lower than the ADC (1.33x10^{-3}mm^2/s) of organized hemorrhage [5]. Our ADC results are thus consistent with the expectation that the fresh hemorrhage is found significantly more often in patients with symptomatic plaques. The observation of a shortened T_2* in symptomatic patients is also consistent with the expectation that symptomatic subjects should show a shift of the type of iron complexes present. The shortened T_2* suggests a shift to aggregate iron complexes that have greater local effects on magnetic susceptibility. The small sample size is a limitation of this study. Further study will include identifying changes in the amount, species, and chemistry of intra-plaque iron during the course of atherosclerosis development. The measurements of T_2* and ADC obtained from 2D ss-SGE-DWEPI in our study revealed significant differences in the hemorrhage morphology of symptomatic and asymptomatic plaques. This approach might be used to characterize high-risk plaque and ultimately identify at-risk patients.

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